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Effects of Slash Burning on Forest Damage from Animals, Insects, Diseases, and Adverse Environment

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ABSTRACT West of the Cascades, slash burning can favor, deter, or have minimal effects on damage from animals, insects, or diseases. Habitat and forage quality have more influence on animal behavior than method of site preparation. Slash burning alone does not appear to be a reliable method of site preparation to benefit either wildlife or timber productivity. Results are variable. The effects of slash burning on insect damage are relatively low west of the Cascades. The buildup of insects in slash serves a beneficial purpose by increasing the surface area available for invasion by decay organisms. Damage to roots of residual trees may attract root-feeding weevils and bark beetles. Fire-damaged trees along edges of clearcuts may become infested by Douglas-fir bark beetles. Slash burning has both direct and indirect effects on pathogens. Rhizina root rot kills newly planted seedlings directly when dormant soilborne spores are stimulated to germinate by high temperatures from fire. Burning has little direct effect on the other major root diseases, primarily because most of the inoculum is protected by soil. Slash burning can be used indirectly to convert root rot susceptible species to a disease tolerant species. Prior to reforestation, residual dwarf mistletoe infection can be effectively cleaned up by slash burning in clearcuts. Foliage diseases are not generally influenced by slash burning. The amount and size of logging slash remaining can influence abiotic seedling problems. Complete slash reduction may allow temperature extremes and excessive seedling mortality from frost and drought. Logging slash as a heat sink ameliorates high and low temperatures and helps retain soil moisture.

The objective of this paper is to provide insight into the effects slash burning has on damage to future tree crops from pests and adverse environment throughout the rotation. This discussion applies to areas of western Oregon and Washington to the crest of the Cascade Mountains. Slash burning may favor, deter, or have minimal effects on these tree damaging agents. Fire influences some pests directly by establishing conditions essential for them to complete life cycles and damage or kill trees. Fire influences other pests indirectly by changing conditions around tree hosts, such as fire injury, or destroying one

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species in favor of another that may escape a pest. The best time to deal with conditions that might lead to later seedling problems is in the planning stage for logging. A burn or no burn decision could make a difference in reforestation success.

In the Pacific Northwest region there are generally fewer insect and disease-related problems west of the Cascade Mountains than on the east side. Conversely, damage to trees from animals is dramatically greater on the west side; interaction among animal species is also greater, and the economic impact is much higher.

Animals, insects, and diseases are the obvious tree damaging pests concerning forest managers, but consideration must also be given to adverse environmental (microclimate) conditions arising from site preparation methods. Animals and adverse environmental factors (weather extremes) are usually the first line of problems confronting newly established forests. With only a few exceptions, insects and diseases move in later, becoming a factor from juvenile through mature age classes. Tree damage from adverse environment is included here because it often mimics damage from other pests.

Pest Management and Impact

Preventive forest pest management is a good way to increase forest productivity; therefore, it is good business to examine the status or potential for forest pests prior to any stand management activity, including slash burning. The land manager's examination may reveal an obvious pest problem which can be solved simply by making a minor change in the management prescription, or it may require help from specialists. There are cases where burning or not burning may influence the pest and the success of the new stand.

Pest impact can be thought of as a shrinkage in productivity over time. In studying this effect, it helps to break the period involved into manageable units by thinking of the impact as the reduction in fiber produced in a pest-damaged stand over a rotation. The difference in final volume between the damaged stand and a similar healthy stand is the loss or impact. It is convenient to break the rotation down into decades to attempt to pinpoint when pest losses might occur (Russell et al. 1986).

Certain pest-caused "losses" are acceptable. Sometimes dead trees benefit birds and other animals. The objective is to make sure there are enough trees nearing the end of rotation to produce the planned volume. In some cases pest-caused losses could be tolerated because timber production is a secondary objective.

A discussion on the mechanics of the integrated pest management (IPM) process helps understand decision-making strategies involving a pest (Russell et al. 1986). It is a useful process that will help the manager consider all factors involving present or potential pests before initiating site preparation (such as slash burning).

The IPM process considers all aspects of host-pest systems and provides forest managers with a data base and guide to pest-related decision making. It is a system that balances pest management with economic, social, biological, and environmental values of the forest or unit in need of treatment. The decision to burn slash would fit into the IPM process.

The manager may call in a complete interdisciplinary team to help with the decision, or—as mentioned earlier—may make the decision. No matter how the decision is made, it is an important part of the process, because what reduces one pest may provide favorable conditions for another.

The manager needs answers to the following questions before proceeding: What is the pest? How much damage is it doing? How much damage can be sustained before it is necessary to do something about it? Can the damage be effectively prevented, controlled, or managed (in this case by burning the slash)?

A pest specialist, if called to assist, would examine at a minimum the following items, then consolidate the findings with the environmental, social, biological, and other concerns to complete the IPM decision: (1) tree host biology/ecology (generally well known): geographic distribution, habitat conditions and microsite requirements, life cycle, stand management options; (2) pest biology/ecology (not always well known): population dynamics, impact on host, pest management options; and (3) state-of-the-art prevention/control availability: *long-term forest planning for loss prevention; *silvicultural or other nonchemical treatment; safety, effectiveness, and cost considerations; adequacy of research; registration of required pesticides (*indicates preferred options).

A complete treatise of the financial part of the decision-making process is given by Russell et al. (1986). A personal computer program is available from the Department of Natural Resources for determining the present net worth of forest management investments such as slash burning and special stump removal for root disease control. The program is written in BASIC and includes cookbook instructions, examples of treated and untreated infected stands, and management regime worksheets. (The program is available from K. Russell, Department of Natural Resources MQ-11, Olympia, Washington 98504.)

Effects on Animal Pests

The strongest factor to emerge from years of animal damage research on site preparation methods is that habitat and forage quality have more influence on animal behavior than method of site preparation. Slash burning changes animal populations for the short term by changing food supply and environment. Steady invasion by seedling-damaging animals following slash burning is common. Slash burning alone does not appear to be a reliable method of site preparation to benefit either wildlife or timber productivity; results are variable (Campbell 1982). Questions regarding slash burning, animal use, and seedling damage remain. The animal damage discussion begins with consumption of tree seeds by animals and progresses through damage to seedlings and larger juvenile trees.

Damage to Seed by Animals

Direct tree seeding was once commonly used for regenerating clearcuts west of the Cascades. As forest nurseries were built in the 1930s, tree planting gradually replaced direct seeding. Strong emphasis was placed on full early stocking of stands. By the late 1970s it was not unusual to plant 700 or more seedlings per acre. The timber market collapse of the early 1980s prompted a reexamination of reforestation practices, resulting in reduced planting density largely because of economic constraints. Today, many organizations are relying on a combination of low density planting and natural seeding on sites where it would be expected to be successful.

Tree seeds are an attractive food for deer mice (*Peromyscus maniculatus*) and certain birds such as Oregon junco (*Junco hyemalis*), long recognized as major seed consumers. Endrin seed treatment was used extensively to protect tree seeds from rodents until environmental concerns in the early 1980s prompted forest managers either to suspend use or to use only limited amounts. Population reduction methods are usually temporary. Deer mice are sometimes killed or driven from slash burned units by the fire, but they rapidly reinvade (Tevis 1956). They have no difficulty finding adequate cover under debris on burned sites. In some cases they are driven from a burned unit to an adjacent fresh logging area, where they may rapidly multiply.

Recent tests by the Olympia Animal Damage Control Laboratory showed high survival of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) germinants when seeds were buried about one-half inch deep on burned slopes and flats. Surface sown seeds were consumed by mice (Campbell 1982). Burned sites that are seeded with native forbs and shrubs for wildlife habitat improvement should first be evaluated for mice or other seed eaters. Further research on burying seed is needed. Two of several questions needing answers are "Could seed be buried on a large scale during harvesting activities?" and "Could seed applied during logging be tested for successful seedling establishment?"

Damage to Seedlings by Animals

Mountain beavers (*Aplodontia rufa*) cause the most seedling mortality of any animal in coastal forests. They damage young trees on over 250,000 acres of commercial forest land each year. They cut seedlings and girdle and undermine saplings. A recent test showed that mountain beavers damaged and killed 40.4% of the Douglas-fir seedlings planted on an unburned site and 53.4% of seedlings on a slash burned site (unpublished data, USDA-APHIS). Most evidence suggests that there is little difference in damage on burned or unburned sites where there are similar numbers of established burrow systems.

These animals have nearly ideal thermal cover underground, and with underground food caches do not need to rely on vegetative cover as much as other forest-feeding mammals do. Their underground burrows gave enough protection in an early summer test burn set by helicopter drip torch that all radio-collared mountain beavers survived. In other tests using tag-recapture data Motobu et al. (1975) found that half or more of mountain beaver populations survived late summer high temperature burns. Forest managers attempting to remove these animals by scarification and piling could end up with higher populations by the creation of new habitat in improperly burned slash piles. Mountain beavers are attracted to slash piles, from which they radiate outward to damage and cut trees. Piled slash should be thoroughly burned and soil piling should be minimized to effectively reduce attractive habitat.

Snowshoe hares (*Lepus americanus*) with adequate hiding cover can severely damage young tree seedlings. One hare can cut 100 tree seedlings per night per acre. Properly timed slash burning and immediate replanting have greatly alleviated early plantation hare problems in recent years. One way to reduce hare damage is with a late summer burn followed by late winter planting. This practice shortens the time that suitable hare habitat ground cover can develop, and the competing vegetation is unable to slow the growth of planted seedlings. The present trend toward less burning may increase hare populations. Generally, unburned sites develop better hare habitat earlier.

Early season burns and partial burns usually stimulate production of plants like woodland groundsel (*Senecio sylvaticus* L.) the year after burning and planting. This plant has no wildlife food value but provides good cover under which hares can hide and feed on seedlings. Late summer burns do not favor groundsel because fall frosts kill germinating plants, and not as much hare cover is produced.

Even with normal variability between burned and unburned sites, the size of hare populations, in general, depends less on whether or not a site was burned than on vegetation density and the amount of logs and debris present within the first four or five years following clearcutting. It appears that the best strategy for reducing hare damage is to minimize woody debris and use planting timing and large seedlings to get tree height beyond feeding reach before competing vegetation and hare habitat develop. The once almost universally applied hare repellent, thiram, is seldom used in nurseries because of occasional allergic reactions by nursery workers or tree planters. This leaves the manager with silvicultural treatment as the best tool to reduce damage.

Roosevelt elk (*Cervus elaphus*) are often attracted to slash burns and prefer small clearcuts where they frequently pull newly planted tree seedlings and browse other small trees. Selective forage seedings are being tried on some areas, but seeding within plantations to reduce damage by elk needs further evaluation. Also, determinations must be made to see if elk will move from plantations into selected forage seeded areas. One such example, although not a burned site, was the debris flow that occurred in the North Fork of the Toutle River from the Mount St. Helens eruption in 1980. A large herd of elk took up residence in the debris flow after the eruption. They were probably attracted by grass seeded in the barren soil, but had historically made high use of the river bottom prior to the eruption.

Sitka willow (*Salix sitchensis* Sanson) log sprouts (part of a revegetation study) that were planted in the small drainages within the debris flow unintentionally became desirable browse for the elk that traversed the small ravines (Russell 1986). The browsing was advantageous since it stimulated dense growth that helped to slow erosion. The elk browsed heavily on conifer seedlings within the debris in the same area, but did not severely damage planted seedlings on the adjacent hillsides.

Red alder (*Alnus rubra* Bong.) is seldom browsed by elk under most conditions, and may be used on some sites without suffering as much as conifer seedlings. Alder seedlings, however, grow more rapidly than conifers, often choking them completely. As they are browsed, multiple stems form a wide profile that can be chewed repeatedly with only occasional damage to the central leader. Meanwhile, nearby conifers may be destroyed.

Meadow voles (*Microtus townsendii*) can become established in burned or unburned sites that have abundant grass for both food and cover. Grasses seeded to reduce other damage problems, such as elk, may have to be removed with herbicides to control cutting and girdling of tree seedlings by voles.

It becomes a matter of which animal is the biggest threat. Tall weeds that die and fall over in a tangled stubble are also capable of supporting large vole populations. For example, sickle keeled lupine (*Lupinus albicaulis* Dougl.) planted in one of the Mount St. Helens revegetation trial treatments was an excellent ground cover which was not grazed by elk, but neither was it compatible with tree seedlings because of heavy shading. The heavy stand also supported a large vole population (Russell 1986). Grasses and dense unpalatable weeds are not compatible with young tree seedlings.

Black-tailed deer (*Odocoileus hemionis columbianus*) cause severe damage when more than about 30% of the trees in a plantation are browsed. Both burned and unburned sites can be damaged in early summer and in late winter when preferred forage is not available.

Preferred native forbs can be seeded in late summer on slash burned or clean logged, unburned sites to provide forage until forest canopy closure occurs (Campbell and Evans 1978). Cats-ear (*Hypochaeris radiata* L.) and a hybrid fleabane (*Erigeron strigosus septentrionalis* Muhl.) do not compete with Douglas-fir seedlings and provide the next early summer forage, which helps offset tree browsing normally done at that time. Two other plants used in the Mount St. Helens revegetation study—birdsfoot-trefoil (*Lotus corniculatus* L.) and New Zealand white clover (*Trifolium repens* L.)—could also supplement browsing by elk or deer. It is important that low growing plants be selected that can occupy sites sufficiently to minimize tall tree-crowding plants until the seedlings get the necessary head start. New Zealand white clover and the trefoils have the added advantage of producing needed nitrogen for planted seedlings.

Native trailing blackberry (*Rubus ursinus* Cham. and Schlect.) becomes established on many burned and nonburned sites except near the coast. The reason for this poor establishment along the coast is unknown. It is the primary winter food for deer. Winter browsing on conifers may occur when trailing blackberry leaves are lacking or have been eaten. The effects of fire on this important food plant are unclear.

Damage to Larger Trees by Animals

Porcupine (*Erethizon dorsatum*) damage to sapling conifer trees has increased west of the Cascades recently. Increasing populations may be related to slash burning or to clearcutting. Poorly burned slash piles with or without woody debris mixed with soil make ideal porcupine den sites (similar to those of mountain beavers). Clean logging and thorough burning of slash piles could reduce suitable habitat; however, the reason for the increase cannot be absolutely tied to fire.

Black bears (*Ursus americanus*) cause locally severe loss of commercial and precommercial trees. Most bear damage starts when trees are about fifteen years old continuing to thirty years or more. There is no clear tie to burned or unburned sites. There does appear to be a tie to lack of late spring forage and closed canopies, but the relationship between damage and available forage is unclear. Sparsely stocked stands and thinned stands are often heavily damaged. It is thought that damage might be prevalent in some areas because bears learn to strip bark and feed on trees in late spring. Bear damage is increasing in reforested burns such as the Tillamook burn in Oregon, but also occurs in the protected Portland, Oregon watershed and unburned portions of the Olympic National Park.

Effects on Insect Pests

Most insect problems arising from slash are associated with Douglas-fir. Western redcedar (*Thuja plicata* Donn), western and mountain hemlocks (*Tsuga heterophylla* [Raf.] Sarg.), (*T. mertensiana* [Bong.] Carr.), and true firs (*Abies* spp.) have less severe pest problems initiated by logging slash. The presence of slash may directly or indirectly affect the fate of insect pests, in particular bark beetles, wood borers, weevils, and others.

Logging slash harbors a multitude of different insects, including both pests and beneficial species. Before it decomposes, slash provides food, shelter, and reproductive sites for several potential pests. The most notable pests are the bark beetles and a few other species attracted to slash during the first year or two after its creation. These insects may be attracted to resinous odors emanating from logging slash or they may increase their populations by breeding in the slash. The end result, in either case, is a large number of insects within a relatively small area. Appropriate prevention of a pest problem then becomes more a matter of timing for slash treatment than how it is treated (Mitchell and Sartwell 1974).

In general, however, there are few insect pest problems arising from logging slash west of the Cascades in Washington and Oregon. In fact, the buildup of insects in slash serves a beneficial purpose by increasing the surface area available for invasion by decay organisms. Burning logging slash nonselectively will affect both pest and beneficial insects.

Bark Beetles

Historically, the Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) is the most important insect pest of mature Douglas-fir forests of the Pacific Northwest. This beetle appears in the aftermath of wind, fire, and other timber calamities where it can attack and kill adjacent green timber. Root diseases, primarily laminated root rot, also predispose stands to outbreaks of this beetle.

The Douglas-fir beetle is generally not known to cause serious postlogging mortality in old-growth Douglas-fir, because slash accumulates away from the residual timber in the open clearcut. A few edge trees may be attacked without slash burning. Edge trees or shelterwood trees singed, but not killed, while burning slash may be killed by beetles. Slash burning to reduce bark beetle buildup is not necessary in today's high utilization forestry. The smaller amount and reduced size of slash material left after logging is not conducive to a Douglas-fir beetle buildup. As timber harvesting moves toward the younger managed forest, infestations by bark beetles from slash should be low. But Douglas-fir bark beetle problems can occur from slash if all conditions are right. Appropriately timed slash burning or other slash treatment could prevent it.

Two other bark beetles, *Pseudohylesinus nebulosis* LeConte and *Scolytus unispinosus* LeConte, build up in logging slash where they can then spread out to adjoining saplings and pole size trees. These two insects could be considered beneficial in that they remove suppressed and weakened trees.

The only word of caution would be the impact on young stands caused by blackstain disease (*Ceratocystis wagnerii* [Kend] Goheen and Cobb) vectored by bark beetles belonging to the genera *Hylastes* and *Hylurgops*—species that breed in fresh stumps and slash. Managers should develop an awareness of this increasingly common disease. See the section on weevils for more details regarding burning.

Wood Borers

Wood boring insects are readily attracted to newly produced slash. Many of these insects are beneficial since they start the wood fragmenting process that is ultimately finished by bacteria, fungi, and weathering. When wood borers invade merchantable logs, utilization losses occur. West of the Cascades, the most common insects that enter and breed in Douglas-fir, western hemlock, and true fir slash are the flat headed fir borer (*Melanophila drummondi* Kirby) and various cerambycids, mostly of the genus *Monochamus*.

When a logging operation produces continuous fresh slash during the spring and summer flight periods of the wood borers, emerging new adults are nearly always attracted back into the slash rather than to nearby standing timber. Where logging is intermittent during the flight period, such as where there are roads or powerline clearings, there is a possibility of minor tree killing in nearby standing timber (Furniss and Carolin 1977). Also, the right conditions of drought and postlogging shock could predispose small numbers of trees, adjacent to clearcuts or within shelterwoods, to attack from wood borers originating in slash.

The western cedar borer (*Trachykele blondeli* Marseul) tunnels into the heartwood of living western redcedars, causing degrade and cull. More damage is sometimes found after logging, possibly by concentration of local insects on fewer trees (Mitchell and Sartwell 1974). The difficulty in detecting the cedar borer in slash has resulted in a recommendation to dispose of all fresh logging residue (Duncan 1979).

Under special timber conditions and other tree stress factors, there may be a need to burn occasionally or otherwise dispose of logging slash to kill wood borer pupae or adults. Burning should be done in midsummer or early fall before the insects emerge. There is no need to burn the slash in normal operations. Slash can also be scattered so that full sun speeds up drying to make it unattractive to insects.

Weevils

Coastal Douglas-fir plantations in Washington, Oregon, and British Columbia, and Sitka spruce (*Picea sitchensis* [Bong.] Carr.), western hemlock, and true fir plantations on Vancouver Island and the Queen Charlotte Islands, British Columbia, are sometimes attacked by a weevil (*Steremnius carinatus* Mannerheim). Larvae develop in the phloem of fresh logging slash and in the roots of the freshly cut stumps. The emerging adults feed on one- and two-year-old seedlings, girdling them at the root crown. The foliage turns red, and root inspection reveals chewing similar to mouse damage.

It is not fully understood whether the presence of fresh slash favors a weevil buildup. Slash burning may eliminate food supplies that these insects would feed on rather than tree seedlings. The best preventive measure is to plant the site immediately following site preparation to get one growing season on seedlings before adult weevils emerge from stumps (Koot 1972). However, as with *Hylastes* and *Hylurgops* species, these weevils are implicated with black-stain disease vectoring. In fact, populations of this weevil complex may increase after stumps are burned, since the root phloem is usually undamaged by fire a few centimeters beneath the soil surface.

Balsam Woolly Aphid

The balsam woolly aphid (*Adelges piceae* [Ratzeburg]), an introduced pest from Europe, damages and kills Pacific silver fir (*Abies amabilis* [Dougl.] Forbes), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), and occasionally grand fir (*Abies grandis* [Dougl.] Lindl.). Infested trees have swollen, gouty twigs and poor crowns, and put on little growth, often dying within two or three years. This aphid is found to about 1,000 meters (3,300 feet) elevation in south coastal British Columbia north to Nanaimo on Vancouver Island and to the Seshelt Peninsula on the mainland (Harris 1978). A quarantine restricts movement of host material within the province. In coastal Washington and Oregon the aphid becomes a problem in true fir stands below 3,000 feet (Mitchell 1966).

In potentially susceptible stands, shade tolerant true firs have moved downslope by regenerating naturally under seral Douglas-firs, and, after logging, replace the Douglas-fir. Historically, well-stocked true fir regeneration was allowed to grow as an understory species without slash treatment. This established conditions for rapid infestation of young true firs by the aphid from nearby infested trees. The released true firs subsequently were reduced to a nonproductive brushfield (Mitchell and Sartwell 1974).

To prevent aphid infestation where nearby true fir overstory is infested, the advanced true fir regeneration must be destroyed and the stand returned to seral Douglas-fir or possibly western hemlock. Burning the slash and planting Douglas-fir is one of the best and perhaps most economical ways to make the change back to the seral species and prevent a serious problem.

Hemlock Bark Maggot

Logging slash plays an indirect role in development of the hemlock bark maggot (*Cheilosia alaskensis* Hunter). Unable to penetrate bark, the small adult flies lay their eggs on or in wounds made in the main stems of western hemlock by bark beetles (*Pseudohylesinus tsugae* Swaine) and (*P. sericeus* Mannerheim). Upon hatching, the maggots enter the beetle wounds, enlarging them, and feed on the sap and soft wood for several years (Furniss and Carolin 1977). The defect caused by the feeding maggots is called black streak or black check in finished lumber.

The bark maggot damage is clearly linked to bark lesions caused by the two *Pseudohylesinus* bark beetles. These beetles breed in stumps and slash but the adults must mature by feeding in the inner bark of hemlock, thus providing a home for the maggot that does the major damage. There is no evidence that burning slash would reduce damage caused by this interaction between flies and bark beetles.

Effects on Beneficial Insects

As already mentioned, a decision not to burn will affect populations of beneficial insects. Mitchell and Sartwell (1974) suggest that the value of insects, mites, and diplopods is significant in the decomposition process of woody material. The final decomposition is largely microbial, but it is the arthropod community that starts the process. Bark beetles, ambrosia beetles, flat and round headed wood borers, carpenter bees, carpenter ants, termites, and dozens of other species serve in the wood fragmentation process. Undoubtedly, fungi and bacteria are carried in by these organisms in an orderly fashion, an important avenue for subsequent research. Studies may indicate that under certain circumstances, slash should be disposed of by means other than burning, thus maintaining the role of the insect fragmenters.

Effects on Forest Diseases

In the Pacific Northwest few studies have directly linked fire with incidence or intensity of diseases. There is need for considerable study in this area. For this paper, forest diseases have been divided into five categories: root diseases, stem diseases, foliage diseases, dwarf mistletoes, and the abiotic "diseases" caused by adverse environment.

Root Diseases

Rhizina root disease (*Rhizina undulata* Fr.) may be the only documented example of fire having a direct impact on a forest disease in the Pacific Northwest. This disease was first noticed in new pine plantations in Great Britain. Dead seedlings were found where tree planters had built warming or "tea time" fires, hence the onetime name "teapot fungus." Spores lie dormant in the soil and germinate only after heating to a high temperature in fires.

After spore germination, the fungus colonizes woody debris and may later infect the roots of newly planted conifer seedlings. Affected seedlings die in typical root disease groups during the summer from the first through about the third year and rarely in older or mature trees (Morgan and Driver 1972). Fortunately, the fungus is a pioneer, occupying a definite niche in newly burned areas and does not last long vegetatively, since it is apparently a poor competitor and requires additional fires to trigger more spore germination.

The disease has caused heavy localized seedling mortality in portions of some clearcuts in western Washington and Oregon. A 1973 survey discovered the fungus on 66 of 277 recently burned Douglas-fir clearcuts in western Washington and Oregon. Frequency of infested clearcuts increased from south to north. Mortality attributable to rhizina root disease averaged 1.3 seedlings per acre compared with the average 34.8 seedlings per acre that died from other causes on the same clearcuts. While the disease has caused spotty and sometimes serious seedling mortality in northwestern Washington, the low overall incidence of loss means the land manager does not have to worry about significant seedling mortality when planning slash burns (Thies et al. 1979). Replanting the year after mortality occurs is usually successful.

Fire does not have a major direct effect on the three major root diseases in the Pacific Northwest: laminated root rot (*Phellinus weirii* [Murr.] Gilbn.), armillaria root disease (*Armillaria mellea* [Vahl.: Fr.] Quel.), and annosus root disease (*Heterobasidion (Fomes) annosum* [Fr.] Bref.). These diseases have in common a saprophytic phase during which they occupy stumps and roots on infested sites. Roots of susceptible trees in the replacement stand may become infected when they contact these pieces of buried inoculum.

Normal slash burning, after clearcutting, is unlikely to kill root rot inoculum. Even in very hot fires, temperatures high enough to kill the fungi in a buried piece of wood are seldom found more than four inches beneath the soil surface. Hollow, laminated root rot-infected stumps may ignite; and, if they were allowed to continue burning, some inoculum could be consumed. However, such stumps are extinguished during fire mop-up. Benefit would be slight if allowed to burn out, since hollow stumps represent only about 15% of infected stumps and contribute little inoculum to the site (unpublished data, W. G. Thies).

An operational control method for reducing laminated root rot and armillaria root disease is to push out the stumps. The question always asked by foresters is: "Do I need to burn the stumps or otherwise dispose of them to get rid of the fungus?"

The answer is no. Removing stumps completely from the soil is sufficient. As stumps dry, the pathogens inside them will die and will not be able to cause more root rot. There will be some incidental root rot infection in the succeeding stand from broken root pieces left behind.

If root rot is a problem, slash burning and stump removal can be combined to reduce overall site preparation costs. It is assumed that soil types would allow burning without site damage. Infection centers are identified before removing stumps in order to keep the area of expensive machine site preparation to a minimum. Nondiseased parts of the unit can then be treated by slash burning or other site preparation prior to reforestation. Infection centers containing substantial recently downed material could burn hotter, possibly damaging the soil. It is important for the manager to realize that slash burning is unlikely to have a direct effect on inoculum reduction; however, burning could be an effective tool in conjunction with more thorough root rot inoculum removal methods for site preparation.

Fire could have an indirect positive effect on a root disease when it changes the forest to species less susceptible to infection. Where other measures such as stump pushing cannot be used (steep slopes), slash burning may be used to alter species composition. Advance regeneration of highly susceptible species such as true firs could be burned after logging and replaced with western hemlock or western white pine (*Pinus monticola* Dougl.) depending on site and elevation. Other choices could be made depending on habitat type. A potential negative effect is that slash burning could create a monoculture that, if infected by residual root rot inoculum, would allow the fungus to move easily from tree to tree through root grafts (Parmeter 1977).

In general, it is unusual in west slope forest management to burn slash under a partly cut stand. When slash is burned in a shelterwood cut or near the edge of a clearcut, residual and edge trees may be heat injured, predisposing them to stem decay and root disease. Damaged trees may become so stressed that they are more easily attacked by root pathogens. In addition, in some situations roots at or close to the soil surface may be killed or injured, providing entry points for root pathogens.

Stem Diseases

The thin-barked species such as western hemlock and true firs are easily damaged by fire. Fires too close to residual trees kill the cambium, resulting in a fire scar. Fire scars, especially those near the ground, provide infection pathways for a variety of pathogens capable of causing butt, stem, and heart rots. Similarly, scars caused by mountain beaver, bear, and porcupines allow pathogens to enter a variety of tree species in burned and unburned sites alike. Trees gradually callus over the wounds and hide them, creating conditions ideal for pathogen entry. Trees are not capable of restoring injured cells like animals do (healing). Animals are cell regenerating systems (creating new cells in place of injured ones), while trees are generating systems (growing new cells over injured ones or callusing). Every injury, whether fire-caused or other, is recorded permanently in the wood over the life of the tree (Shigo 1986).

Perhaps the most common place where slash burning occurs near or under residual trees is where partial land clearing is being done, such as around homesites, in recreation areas, or for road building. Protection of trees from injury is often either nonexistent or poorly done. The senior author has observed fire-scarred boles and scorched crowns combined with machine wounding, root damage, soil compaction, and back filling that jeopardized health and survival of 100% of the remaining trees. Tree failure is low the first few years after injury but increases to a dangerous level after fifteen to twenty years because of injury-induced decay. The original injury, after becoming partly hidden by normal callusing processes, is usually only detectable by trained foresters or arborists. Probability of tree failure from hidden decay becomes high and often occurs without warning during storms, threatening both life and property.

Western white pine is gaining favor among foresters as a reforestation species, after a long absence because of fear of excessive loss from white pine blister rust (*Cronartium ribicola* J. C. Fisch.). Slash burning could indirectly increase rust incidence where there is intent to reforest with white pine by favoring the *Ribes* genus, the alternate host of the rust fungus (Quick 1972). Silviculturists should examine stands carefully to ensure that *Ribes* species would not be stimulated by burning. Nearby infection from *Ribes* species in adjoining stands is also a factor and should be considered in future burn plans.

Van Arsdel (1961) has presented evidence that the incidence of eastern white pine blister rust is influenced by changing microclimate when ground cover is burned. The fact that approximately 90% of western white pine blister rust cankers are found within 6 feet of the ground suggests that microclimate influences rust infection (unpublished data, K. W. Russell). Suppressing brush invasion on certain sites by slash burning prior to planting white pine may reduce early rust infection by lowering the relative humidity near the ground.

Foliage Diseases

Foliage diseases may be locally damaging, but on a regional basis are of low economic importance. Native conifer seedlings are not fire resistant and could not survive a burn. Fire could be used to reduce inoculum on needles that fall to the forest floor, but sufficient needles carrying inoculum hang on healthy foliage to cause reinfection. Fires would have to occur annually in order to control pathogens on fallen needles. At present, slash burning is not known to be effective in controlling or preventing any of the foliage diseases of western conifers.

Perhaps the best example of the use of fire for disease control is on brown spot needle blight (*Scirrhia acicola* [Dearn.] Siggers), a needle disease of longleaf pine in the southeastern United States. When natural regeneration is used, rapid ground fires provide conditions for natural seeding and destroy spores on any diseased seedlings present. Follow-up winter burning reduces spore inoculum until the trees grow out of the grass stage (Croker and Boyer 1975). The disease has little effect after seedlings escape the grass stage.

Dwarf Mistletoes

Fire is probably the most influential factor governing distribution and abundance of the dwarf mistletoes (Alexander and Hawksworth 1975). Hemlock dwarf mistletoe (*Arceuthobium tsugense* [Rosendahl]), the only species of consequence to coastal forest managers, infects western and mountain hemlocks as principal hosts. It is also found on true firs, especially Pacific silver fir and lodgepole pine (*Pinus contorta* Dougl.) when they are in association with the hemlocks; but the parasite is not a serious management problem on these two hosts (Hawksworth and Weins 1972). Hemlock dwarf mistletoe will not infect Douglas-fir. This endemic plant parasite requires a live host and causes spike tops, distinctive brooming, stem cankers, growth loss, and mortality.

Slash burning is one of the most effective tools for preventing dwarf mistletoe reinfection in a new stand of western or mountain hemlock. The best time to control the parasite is when the merchantable timber is clearcut. Shelterwood cuts in infected overstories are not recommended unless the overstory is removed within a very few years. Skyline or highlead logged units containing old-growth western hemlock often contain a large amount of advance hemlock regeneration that is infected with dwarf mistletoe. These trees carry latent infections which blossom with copious mistletoe seed after logging to infect new hemlock regeneration. The infected hemlock residuals must be destroyed to prevent infection of the subsequent stand. Slash burning, special timber sale clauses requiring all stems to be cut, machine site preparation, and herbicides are all effective methods for treatment.

Some stands in the Cascade Mountains and coastal range have Pacific silver fir mixed with hemlock, and the advance regeneration is also mixed. It may be desirable to use this advance regeneration for the next stand except for the mistletoe-infected hemlock. If such a stand were burned, the true fir would also be destroyed. A careful management decision must be made either to burn both species or to destroy the diseased hemlock. While slash burning is not a requirement to control hemlock dwarf mistletoe, it is a good method to accomplish the task. Advance regeneration that was exposed to infected overstory trees may be destroyed in any fashion before the new seedlings become established.

Little or no dwarf mistletoe will be found in stands that originated after fire (Russell 1971, 1976, Wellwood 1956). Surveys made in the late 1960s by Russell found that Washington State Department of Natural Resources clearcuts on the Olympic Peninsula burned up to ten years earlier had little or no dwarf mistletoe in the thickly regenerated stands. Department policy had been to clearcut and follow with slash burning and planting. This policy did an excellent job, almost by accident, of preventing dwarf mistletoe infection. The primary objective was to reduce slash and provide mineral soil exposure for planting and natural regeneration.

Slash burning is a very effective method for dealing with hemlock dwarf mistletoe in the coast ranges and Cascade Mountains. When soil properties, air quality, or other restrictions prohibit burning, other methods of removing residual infected advance regeneration will work.

Adverse Environment

The term "adverse environment" can be thought of as climate-caused phenomena that damage vegetation. Synonymous terms are "physiological," "abiotic," and "noninfectious" diseases. These would include such weather phenomena as winter desiccation, frost injury, drought, flooding, and other weather or microclimatic effects. Adverse environment problems are included as pests because their injury types so often resemble pest damage.

Slash burning and other methods of clean site preparation can cause reduced survival of new seedlings in clearcuts where there may be problems with adverse environment, especially on south facing slopes and lower rainfall areas. Problems would include a worsening of existing frost pockets, restricted air drainage depressions after timber is removed, radiation cooling on high elevation sites, east winds, south-southwest aspects, moisture loss from rocky soils, and others.

Mature forests growing in restricted air drainage depressions are usually not affected by pooling of cold air. Trees growing in the bottoms of depressions tend to be taller than those on the slopes, smoothing the roughness of the terrain at the radiation-receiving canopy level. The forest cover acts as a huge thermostat, smoothing the temperature extremes. After logging, and more especially after fire, the true depth of the depression is exposed and the cold surrounding air flows into it, effectively shortening the growing season in its lowest parts. If the air drainage outlet is restricted, new seedlings may be injured during dormancy, or growth may be slowed or damaged in the growing season. It may take as long as twenty years and one or more replantings before young trees gain enough mass and height to escape nearly annual damage.

Recognition of potential cold air sinks ahead of logging allows modification of the cutting unit shape to promote better air drainage. The decision to omit fire may provide sufficient woody debris cover to protect tree seedlings. A shelterwood cut also could be used to reduce heat loss and minimize cold air pooling.

Upper elevation plantations often take years and more than one replanting before trees become successfully established. The flattened tops of the Black Hills in the Capital Forest southwest of Olympia provide a classic example. Wildfires burned over the ridgetops several times, leaving a thin soil with little woody material or other vegetation to protect new tree seedlings. Small trees simply could not exert enough influence on these tough sites to modify the severe temperature extremes. Some kind of cover or roughening of the landscape by other vegetation was needed before the trees could grow at normal rates. Small patch clearcuts or shelterwood cuts without burning would have been better solutions for successful regeneration. It has taken more than twenty-five years to establish timber stands on a few of these upland sites. Animal damage was also a factor in losing trees.

Slash burning may not be advisable in some areas because it destroys woody material and other plants that ameliorate temperature extremes and slow moisture loss during dry periods. In these situations it is desirable to retain some vegetation, large logging debris, and brush as a heat reservoir to provide protection from radiation cooling and full exposure to the sun. Small patch clearcuts will allow adjoining stands to protect the new forest. In frost prone areas a cold-resistant species like shore pine (lodgepole) might be used as a nurse crop before a more desirable conifer is planted. Western white pine could be used as a substitute instead of a nurse species. Pine candles, with their greater mass and needle protection, are able to tolerate more frost than the naked buds of Douglas-fir. In order for tree seedlings to absorb reradiated heat, planters should be instructed to place them near large woody debris but not adjacent to stumps, because of the potential of root rot infection.

Soils containing more than about 50% rock (gravel or any form) and/or a shallow hardpan may cause excessive Douglas-fir plantation failure about four out of every twenty to twenty-five years, or whenever June to September rainfall is below about 3.5 inches (Russell 1987). Drought-caused tree killing occurs at any age from one to twenty years on a large scale and intermittently on older trees. Lodgepole pine or western white pine may be substituted for drought-susceptible Douglas-fir if the area was clearcut, or Douglas-fir may be planted if a shelterwood was used. Shelterwood cutting is recommended, since the overstory keeps the drought-prone soils cooler, retains some moisture through hot spells, and reduces early regeneration mortality.

Slash burning on rocky soils is not recommended because of the need to retain organic matter and woody debris for moisture and temperature protection.

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